

Modeling of Criteria Air Pollutant Emissions from Selected Nigeria Petroleum Refineries

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Abstract

The dispersion models were used to estimate or predict the concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases. In this study, the Industrial Source Complex Short Term (ISCST3) emission dispersion model was used to measure the ground level concentration of criteria air pollutants within 50 km radius of location. This model considered emissions from major point sources of pollutants in four existing and twenty-three proposed Nigeria petroleum refineries. The obtained ground level concentration for 24-hr averaging periods of the criteria air pollutants at sensitive receptor around each of the refineries was compared with the National Ambient Air Quality Standards (NAAQS) of Nigeria, World Bank and World Health Organization (WHO) to determine their level of compliance. The highest ground level concentration predicted to be 450 - 1875 $\mu\text{g}/\text{m}^3$ for 24-h averaging period was obtained at Tonwei Oil Refinery, Ekeremor Local Government, Bayelsa State, while the lowest ground level concentration predicted to be 0.0099 - 0.1 $\mu\text{g}/\text{m}^3$ for 24-h averaging period was obtained at Amakpe International Refinery, Eket Local Government, Akwa Ibom State. Percentage set limits of criteria air pollutants ranging from 0.02% to 94.5% are within the set standard limits and no health risk is associated with areas around the plant's locations while percentage set limits of criteria pollutants ranging from 1.1 to 55.6 folds of the standards exceed the maximum permitted limits, hence affecting areas around the plants. The air quality standards guiding petroleum refinery emissions must be strictly considered, in order to ensure that the ground level concentrations do not exceed the required standard limits and prevent the adverse effects of air pollution in the Nigeria airshed.

Keywords

Air Quality Standards, Ground Level Concentration, Nigeria Petroleum Refinery

1. Introduction

Each year industrial facilities discharge pollutants into the environment, releasing large amounts of pollutants leading to respiratory, neurological and reproductive disorders, and cancers [1]. Nigeria is presently a major emitter of criteria air emissions: carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter less than 10.0 microns in diameter (PM₁₀), sulphur dioxide (SO₂) and volatile organic compounds (VOCs) which comes from number of sources within a petroleum refinery including equipment leaks (from valves or other devices), high-temperature combustion processes, etc [2]. The Industrial Source Complex Short Term (ISCST3) air dispersion modeling tool is a steady state Gaussian plume model which can be used to assess pollutant concentrations, and/or deposition fluxes from a wide variety of sources are associated with an industrial source complex [3]. It was used to predict the ground level concentrations of criteria air pollutants from the four major existing and twenty-three proposed petroleum refineries in Nigeria, within 50 km radius of location from point sources of emission in the refineries, for the prevailing meteorological conditions assuming a “worst case scenario” *i.e.* 100% operation rate. The model is used to determine whether existing or proposed new industrial facilities are or will be in compliance with the National Ambient Air Quality Standards (NAAQS). Air pollution models constitute a set of formulae that take into account sources of pollution in a given area, the amounts of pollutants emitted by each source, chemical reaction transformations, different meteorological conditions and topographical features, and other factors that affect dispersion of pollutants. [4] defined the process of computer modeling of air pollution as the ability to use computers to solve basic equations that described the dynamics of meteorological and air pollution phenomena, and ultimately, the adverse effects of air pollution. The basis for most of those models was the complete equation for Gaussian Dispersion Modeling of continuous and buoyant air pollution plumes [5]. Previous studies on investigation on emissions using ISCST3 include [5]-[7]. This study is carried out to investigate the atmospheric conditions of the petroleum refineries in Nigeria and identify the environmental impacts of emissions of criteria pollutants in the area of influence. Determinations of their ground level concentrations and comparison with the National Ambient Air Quality Standards (NAAQS) of Nigeria, World Bank and World Health Organization (WHO) will indicate the level of air quality management required around Nigerian petroleum refineries.

2. Study Areas

As shown in **Figure 1**, Nigeria has 4 existing refineries; Kaduna Refining and petrochemical company (KPRC) located at Chikun Local Government of Kaduna State operating at 110,000 bbl/day; Warri Refining and petrochemical company (WRPC) located at Warri southwest local government of Nigeria's Delta State with an installed capacity of 125,000 bbl/day; Port Harcourt Refining Company (PHRC) has two refineries at Alesa-Elеме, near Port Harcourt in Nigeria's Southern Province, Rivers State. Port Harcourt I refinery has installed capacity of 60,000 bbl/day while Port Harcourt II refinery is the complex new refinery with installed capacity of 150,000 bbl/day [8] [9]. Due to scarcity of petroleum products, 23 proposed refineries have been licensed in Nigeria to ensure availability of the products (**Figure 1**), which includes the following with their installed capacities; Resources refinery and petrochemical Limited located in Ikot Abasi local government area of Akwa Ibom state (100,000 bbl/day); Amakpe International Refinery, Eket local government of Akwa Ibom state with production capacity of (12,000 bbl/day); Rehoboth Natural Resources Limited (12,000 bbl/day), Immingiri, Yenekoa local government of Bayelsa state; Amexum Corporation (100,000 bbl/day), Akpabuyo local government of Cross river state; Antonio Oil (27,000 bbl/day), Ipokia local government of Ogun state; Gasoline Associates International Limited Refinery (100,000 bbl/day), Ipokia local government of Ogun state; Ologbo Refinery Company Nigeria Limited (12,000 bbl/day), Ikpoba Okha local government of Edo state; Ode Aye Refinery Limited (100,000 bbl/day), Okiti pupa local government area of Ondo state; Orient Petroleum Resources Limited (55,000 bbl/day), Anambra West local government area of Anambra state; Qua Petroleum Refinery Limited (100,000 bbl/day), Ibeno local government of Akwa Ibom state; ChaseWood Consortium Nigeria Limited (70,000 bbl/day), Eket local government area of Akwa Ibom state; Clean Water Refinery (60,000 bbl/day), Elеме local government area of Rivers state; Niger Delta Refinery & Petrochemical Limited (100,000 bbl/day), Warri-South local government area of Delta state; NSP Refineries and Oil Services Limited (120,000 bbl/day), Andoni local government area of Rivers state; RIVGAS Petroleum and Energy Limited (30,000 bbl/day), Port Harcourt local government area of Rivers state; Sapele Refinery Limited located in Okpe-Sobo, Sapele local government area of Delta state (100,000 bbl/day); Starrex Petroleum Refinery (100,000 bbl/day), Elеме local government area of

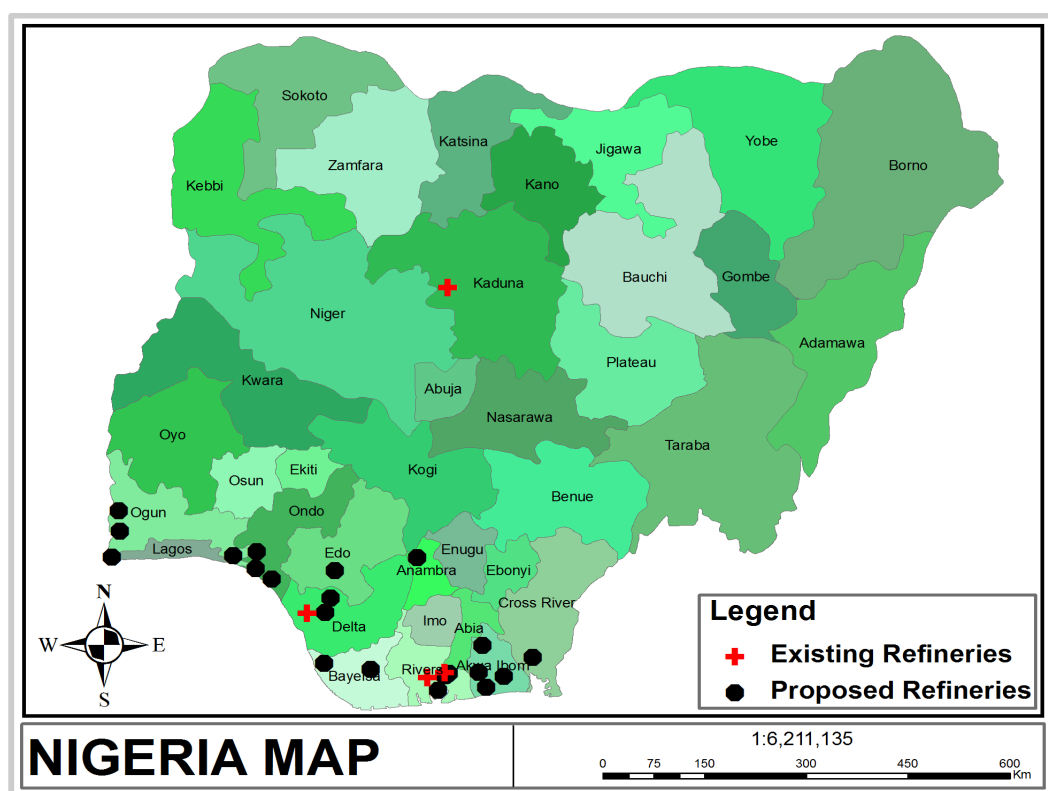


Figure 1. Map of Nigeria showing the existing and proposed Refineries.

Rivers state; Total Support Limited (12,000 bbl/day), Calabar Mnincipal local government area of Cross River state; Union Atlantic Petroleum Limited (100,000 bbl/day), Badagry local government area of Lagos state; Tonwei Oil Refinery (200,000 bbl/day), Ekeremor local government area of Bayelsa state; Ilaje Refinery and Petrochemicals (100,000 bbl/day), Ilaje local government area of Ondo state; Southwest Refinery and Petrochemical Company (100,000 bbl/day) is located in Ogun Waterside local government area of Ogun state; Owena Oil and gas Limited (100,000 bbl/day), Ilaje local government area of Ondo state [8]-[10].

3. Methodology

ISCST3 model uses steady state Gaussian plume equation to model emissions from point sources, including flares, process heaters, steam boilers and fluid catalytic cracking unit. This model considered emissions from the stacks of existing refineries and proposed petroleum refineries in Nigeria. Criteria air pollutants modeled for the ground level concentration include CO, NO_x, PM₁₀, SO₂ and VOC. The standards of ambient air quality as reported by NAAQS, WB and WHO is shown in [Table 1](#). Major sources of emissions and parameters used as input to the air dispersion modeling for each of the refineries are shown in [Table 2](#) and [Table 3](#). Some proposed refineries have similar operation rate, hence will have the same emission sources and dispersion model parameter. The ISC-AERMOD View air dispersion modeling tool developed specially for Microsoft Windows and runs under Windows 95/98/Me/NT/2000 and XP was employed in this study. This is a complete and powerful air dispersion modeling package which incorporates the popular U.S. EPA models into one interface: AERMOD, ISCST3, and ISC-PRIME. ISCST3 dispersion model interfaces [1]. The ISCST3 interface was used in this study which uses pathways that compose the run stream file as the basics for its functional organization. These pathways include:

- i) Control Pathway (CO): Where the modeling scenario (worst case scenario *i.e.* 100% operation rate), the pollutants (CO, NO_x, SO₂, VOC and PM) and the averaging periods (24-hr) are specified.
- ii) Source Pathway (SO): Where the sources of pollutant emissions (point sources of pollutants in the refinery-process heaters, fluid catalytic cracking units, steam boilers and flares) are defined.

Table 1. Standards of ambient air quality.

S/N	Pollutants	Averaging Period	Maximum Concentration ($\mu\text{g}/\text{m}^3$)		
			NAAQS	World Bank	WHO
1	CO	24-Hr	11,400	-	-
2	NO _x	24-Hr	75	150	-
3	SO ₂	24-Hr	26	-	20
4	PM	24-Hr	250	80	50
5	VOC	24-Hr	6000	-	-

Source: FEPA (1991) [11]; World Bank (1998) [12]; WHO (2005) [13].

Table 2. Emission sources and dispersion model parameters for existing refineries.

Plant Name	Stack	Discharge Temperature (k)	Stack Diameter (m)	Exit Velocity (m/s)	Release Height (m)	Emission (g/s)				
						PM ₁₀	SO ₂	NO _x	VOC	CO
Kaduna Refining & Petrochemical Company (KRPC) 110,000 BPSD	^a Flare 1	1540	6.6	4.52	66	-	-	0.001	0.003	0.005
	Flare 2	1540	6.6	4.52	66	-	-	0.001	0.003	0.005
	Flare 3	1540	6.6	4.52	66	-	-	0.001	0.003	0.005
	^b FCCU	330	2.75	23.47	67	-	54.5	7.9	24.3	1510.4
	^b Boiler 1	550	2.18	9.05	30	-	304.1	1420.1	-	106
	Boiler 2	550	2.18	9.05	30	-	304.1	1420.1	-	106
	Boiler 3	550	2.18	9.05	30	-	304.1	1420.1	-	106
	^b Heater 1	660	2.01	8.03	43	2.1	45.1	173.2	1.0	15.8
	Heater 2	660	2.01	8.03	43	2.1	45.1	173.2	1.0	15.8
Port Harcourt Refining Company I (PHRC) 60,000 BPSD	^a Flare 1	840	1.1	2.47	36	-	-	0.0003	0.0006	0.002
	Flare 2	840	1.1	2.47	36	-	-	0.0003	0.0006	0.002
	^b FCCU	180	1.5	12.8	37	-	12.5	2.0	5.6	347.7
	^b Boiler 1	300	1.19	4.94	16	-	59.6	278.7	-	20.8
	Boiler 2	300	1.19	4.94	16	-	59.6	278.7	-	20.8
	^b Heater 1	360	1.1	4.38	24	0.6	13.4	51.6	0.3	4.7
	Heater 2	360	1.1	4.38	24	0.6	13.4	51.6	0.3	4.7
Port Harcourt Refining Company II (PHRC) 150,000 BPSD	^a Flare 1	2100	2.75	6.17	90	-	-	0.002	0.004	0.01
	Flare 2	2100	2.75	6.17	90	-	-	0.002	0.004	0.01
	Flare 3	2100	2.75	6.17	90	-	-	0.002	0.004	0.01
	Flare 4	2100	2.75	6.17	90	-	-	0.002	0.004	0.01
	^b FCCU	450	3.75	32.01	92	-	103.5	14.9	46.3	2877
	^b Boiler 1	750	2.97	12.35	41	-	267.8	1250.7	-	93.4
	Boiler 2	750	2.97	12.35	41	-	267.8	1250.7	-	93.4
	^b Boiler 1	750	2.97	12.35	41	-	267.8	1250.7	-	93.4
	Boiler 2	750	2.97	12.35	41	-	267.8	1250.7	-	93.4
	^b Heater 1	900	2.75	10.95	59	3.7	80.2	308.1	1.7	28
	Heater 2	900	2.75	10.95	59	3.7	80.2	308.1	1.7	28

Continued

Warri Refining & Petrochemical Company (WRPC) 125,000 BPSD	^a Flare 1	1750	2.29	5.13	75	-	-	0.001	0.003	0.007
	Flare 2	1750	2.29	5.13	75	-	-	0.001	0.003	0.007
	Flare 3	1750	2.29	5.13	75	-	-	0.001	0.003	0.007
	Flare 4	1750	2.29	5.13	75			0.001	0.003	0.007
	^b FCCU	375	3.13	26.68	76	-	67.3	9.7	30	1870.1
	^b Boiler 1	625	2.48	10.29	34	-	228.8	1068.3	-	79.8
	Boiler 2	625	2.48	10.29	34	-	228.8	1068.3	-	79.8
	Boiler 3	625	2.48	10.29	34		228.8	1068.3	-	79.8
	^b Heater 1	750	2.29	9.13	49	2.9	61.3	253.3	1.3	21.4
	Heater 2	750	2.29	9.13	49	2.9	61.3	253.3	1.3	21.4

Source: ^aAbdul-Wahab *et al.* (2001) [14]; ^bStell (2000) [15]; ^cUSEPA 1989 [16].

Table 3. Emission sources and dispersion model parameters for proposed refineries.

Plant Name	Stack	Discharge Temperature (k)	Stack Diameter (m)	Exit Velocity (m/s)	Release Height (m)	^c Emission (g/s)				
						PM ₁₀	SO ₂	NO _x	VOC	CO
Resource Refinery & Petrochemical, Onne 100,000BPSD	^a Flare 1	1400	1.83	4.11	60	-	-	0.001	0.002	0.004
	Flare 2	1400	1.83	4.11	60	-	-	0.001	0.002	0.004
	Flare 3	1400	1.83	4.11	60	-	-	0.001	0.002	0.004
	^b FCCU	300	2.5	21.34	61	-	34.7	5.0	15.6	965.9
	^b Boiler 1	500	1.98	8.23	27	-	165.7	773.9	-	57.8
	Boiler 2	500	1.98	8.23	27	-	165.7	773.9	-	57.8
	^b Heater 1	600	1.83	7.3	39	1.7	37.3	143.2	0.8	13
	Heater 2	600	1.83	7.3	39	1.7	37.3	143.2	0.8	13
NSP Refineries & Oil services Limited, Andoni 120,000BPSD	^a Flare 1	1680	2.2	4.93	72	-	-	0.001	0.003	0.006
	Flare 2	1680	2.2	4.93	72	-	-	0.001	0.003	0.006
	Flare 3	1680	2.2	4.93	72	-	-	0.001	0.003	0.006
	Flare 4	1680	2.2	4.93	72			0.001	0.003	0.006
	^b FCCU	360	3.0	25.61	73	-	50.1	7.1	22.3	1390.9
	^b Boiler 1	600	2.38	10.0	33	-	238.6	1114.4	-	83.2
	Boiler 2	600	2.38	10.0	33	-	238.6	1114.4	-	83.2
	^b Heater 1	720	2.2	8.76	47	2.5	53.7	206.1	1.1	18.7
	Heater 2	720	2.2	8.76	47	2.5	53.7	206.1	1.1	18.7
	^a Flare 1	840	1.1	2.47	36	-	-	0.0003	0.0006	0.002
Clean Water Refinery, Elemo (60,000BPSD)	Flare 2	840	1.1	2.47	36	-	-	0.0003	0.0006	0.002
	^b FCCU	180	1.5	12.8	37	-	12.5	2.0	5.6	347.7
	^b Boiler 1	300	1.19	4.94	16	-	59.6	278.7	-	20.8
	Boiler 2	300	1.19	4.94	16	-	59.6	278.7	-	20.8
	^b Heater 1	360	1.1	4.38	24	0.6	13.4	51.6	0.3	4.7
	Heater 2	360	1.1	4.38	24	0.6	13.4	51.6	0.3	4.7

Continued

RIVGAS Petroleum & Energy Limited, Port Harcourt (30,000BPSD)	^a Flare 1	420	0.55	1.23	18	-	-	0.00007	0.00002	0.0004
	Flare 2	420	0.55	1.23	18	-	-	0.00007	0.00002	0.0004
	^b FCCU	90	0.75	6.4	18	-	3.1	0.4	1.4	87
	^b Boiler 1	150	0.59	2.47	8	-	14.9	69.6	-	5.2
	Boiler 2	150	0.59	2.47	8	-	14.9	69.6	-	5.2
	^b Heater 1	180	0.55	2.19	12	0.2	3.4	12.9	0.07	1.2
Towei Oil Refinery 200,000 BPSD	Heater 2	180	0.55	2.19	12	0.2	3.4	12.9	0.07	1.2
	^a Flare 1	2800	3.66	8.22	120	-	-	0.11	0.20	0.70
	Flare 2	2800	3.66	8.22	120	-	-	0.11	0.20	0.70
	Flare 3	2800	3.66	8.22	120	-	-	0.11	0.20	0.70
	Flare 4	2800	3.66	8.22	120	-	-	0.11	0.20	0.70
	^b FCCU	600	5.0	42.68	122	-	2158.7	312.85	962.9	60,006
	^b Boiler 1	1000	3.96	16.46	54.3	-	23,040	107605.4	-	8,033.4
	Boiler 2	1000	3.96	16.46	54.3	-	23,040	107605.4	-	8,033.4
	Boiler 3	1000	3.96	16.46	54.3	-	23,040	107605.4	-	8,033.4
	Boiler 4	1000	3.96	16.46	54.3	-	23,040	107605.4	-	8,033.4
	^b Heater 1	1200	3.66	14.6	78.6	229.86	5183.0	19904.66	107.7	1,811.1
	Heater 2	1200	3.66	14.6	78.6	229.86	5183.0	19904.66	107.7	1,811.1
Orient Petroleum Resource Limited 55,000 BPSD	^a Flare 1	770	1.01	2.26	33	-	-	0.001	0.03	0.04
	Flare 2	770	1.01	2.26	33	-	-	0.001	0.03	0.04
	^b FCCU	165	1.38	11.74	34	-	368.48	55.62	163.3	10,167
	^b Boiler 1	275	1.09	4.53	15	-	1741.5	8137.76	-	608.33
	Boiler 2	275	1.09	4.53	15	-	1741.5	8137.76	-	608.33
	^b Heater 1	330	1.01	4.02	22	17.38	392.81	1505.19	10.43	139.05
Amakpe Internatna Refinery 12,000 BPSD	Heater 2	330	1.01	4.02	22	17.38	392.81	1505.19	10.43	139.05
	^a Flare 1	168	0.22	0.49	7	-	-	0.0004	0.001	0.003
	Flare 2	168	0.22	0.49	7	-	-	0.0004	0.001	0.003
	^b FCCU	36	0.3	2.56	7	-	13.70	2.43	10.43	483.19
	^b Boiler 1	60	0.24	0.98	3	-	560.05	2602.24	-	209.24
	Boiler 2	60	0.24	0.98	3	-	560.05	2602.24	-	209.24
	^b Heater 1	72	0.22	0.88	5	1.05	1.05	73.00	0.35	0.69
	Heater 2	72	0.22	0.88	5	1.05	1.05	73.00	0.35	0.69
	^a Flare 1	980	1.28	2.88	42	-	-	0.01	0.03	0.07
	Flare 2	980	1.28	2.88	42	-	-	0.01	0.03	0.07
Chase wood Consortiu Nigeria Limited 70,000 BPSD	^b FCCU	210	1.75	14.94	43	-	590.95	83.42	264.1	13.90
	^b Boiler 1	19	350	1.39	19	-	2930.4	13678.8	-	983.8
	Boiler 2	19	350	1.39	19	-	2930.4	13678.8	-	983.8
	^b Heater 1	420	1.28	5.11	28	31.28	636.14	2436.81	13.90	222.48
	Heater 2	420	1.28	5.11	28	31.28	636.14	2436.81	13.90	222.48

Source: ^aAbdul-Wahab *et al.* (2001); ^bStell (2000); ^cUSEPA (1989).

iii) Receptor Pathway (RE): where the receptors which determine the air quality impact at specific locations. Specifically, 50 km radius within each refinery was given adequate attention.

iv) Meteorological Pathway (ME): Where the atmospheric condition of the areas being modeled is defined, so it can be taken into account when determining the distribution of air pollution impacts for the area. Due to lack of upper air observations in Nigeria airport, meteorological database for the project location was combined using data from Cotonou meteorological observations. Cotonou has winds having prevalence for a southwesterly direction which is consistent with the winds observed in the refineries.

v) Terrain Grid Pathway (TG): Where the option of gridded terrain data to be used in calculating dry depletion in elevated or complex terrain is specified. Elevated terrain is relevant to this study.

(vi) Output Pathway (OU): Where you define which output results are necessary to meet the needs of the air quality modeling analysis. The resultant output is the ground level concentration of pollutants as shown in **Figure 2** and **Figure 3**.

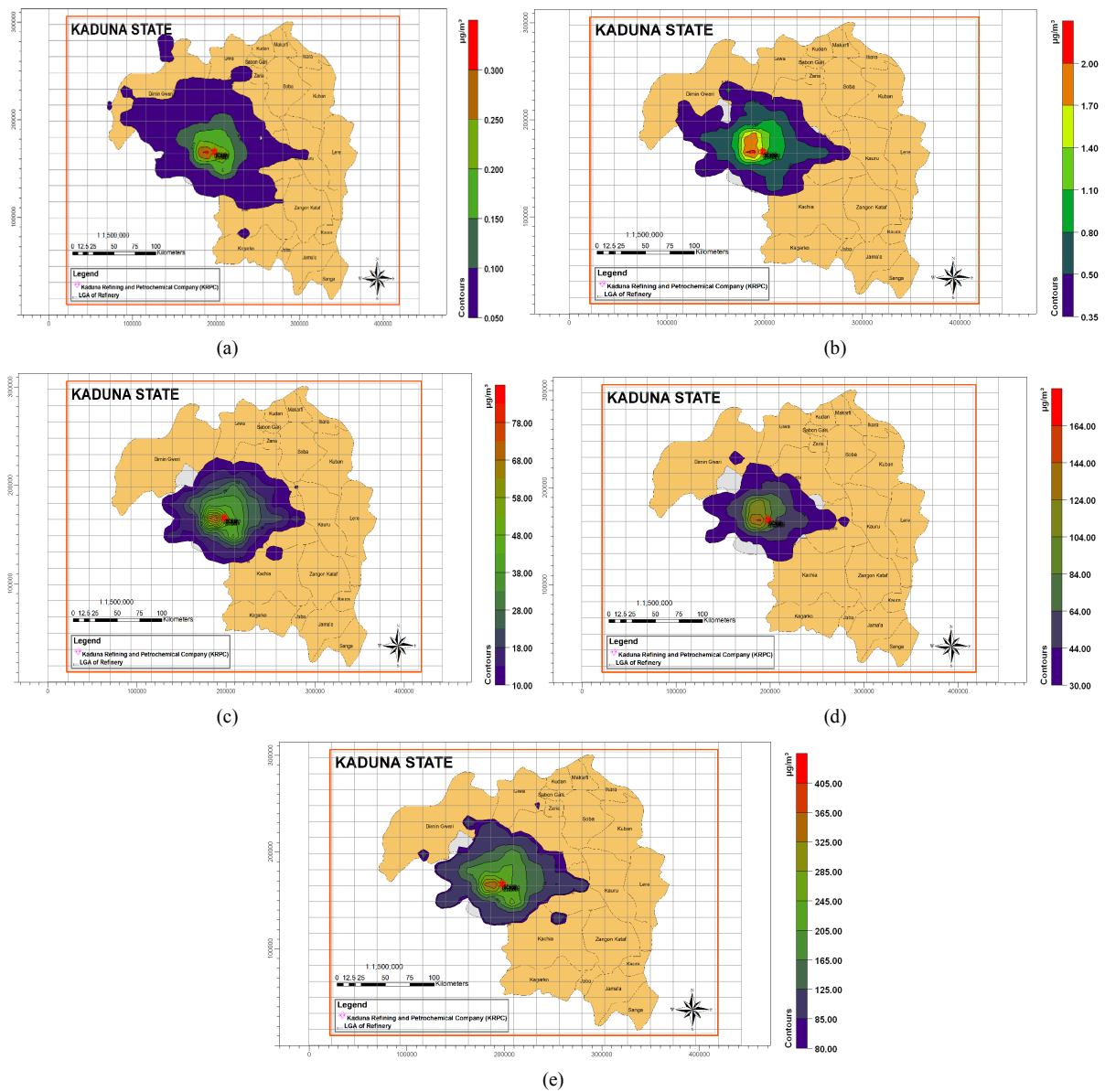


Figure 2. Predicted 24-hr Ground Level Concentrations of Criteria Pollutants from Kaduna Refining and Petrochemical Company, Kaduna State. (a) Predicted 24-hr PM_{10} Concentrations; (b) Predicted 24-hr VOC Concentrations; (c) Predicted 24-hr SO_2 Concentrations; (d) Predicted 24-hr NO_x Concentrations; (e) Predicted 24-hr CO Concentrations.

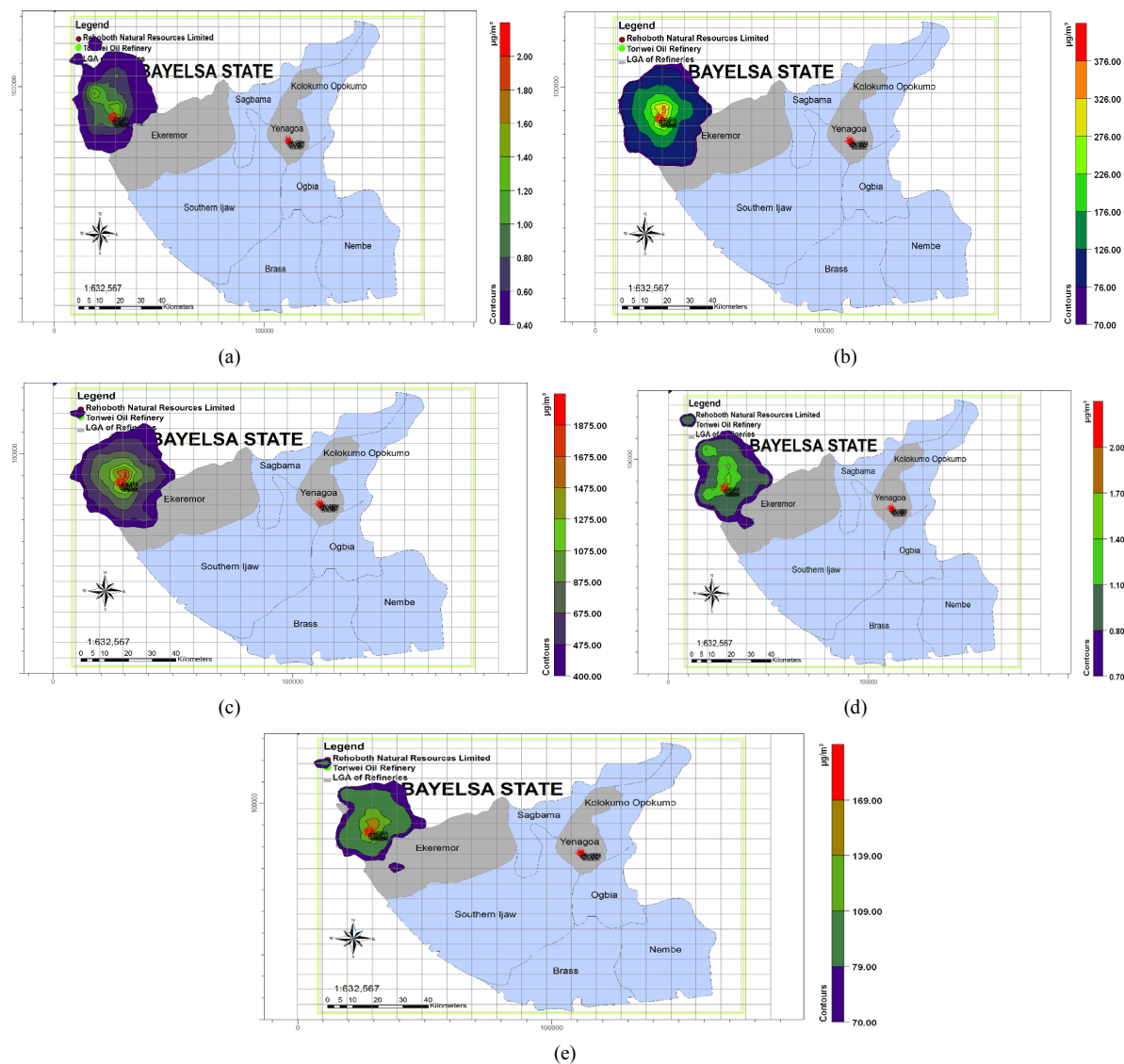


Figure 3. Cumulative 24-hr Ground Level Concentrations of Criteria Pollutants from Bayelsa state refineries. (a): Cumulative 24-hr PM₁₀ Concentrations; (b) Cumulative 24-hr SO₂ Concentrations; (c) Cumulative 24-hr NO_x Concentrations; (d) Cumulative 24-hr VOC Concentrations; (e) Cumulative 24-hr SO₂ Concentrations.

From the existing and proposed refineries, the ground level concentration (glc) of the criteria air pollutant were computed and compared with the standards of ambient air quality derived from National Ambient Air Quality Standards (NAAQS) of Federal Ministry of Environment (FMENV), that of the World Bank environmental guidelines and World Health Organization (WHO) standards to determine their level of compliance (Table 4 and Table 5).

4. Results and Discussion

An air quality impact on refineries is important to assess the impacts of emissions from petroleum refinery operations on their environment. Table 2 and Table 3 shows the emission sources and dispersion model parameters for the existing and proposed refineries these include the emission estimate of criteria pollutants from point sources (FCCU, Process heaters, Flares, Steam boilers) of emissions from the refineries. The dispersion modeling outputs from the ISC-AERMOD View (for the existing and proposed refineries in Nigeria) for 1-hour, 8-hour, 24-hour and annual averaging periods for the criteria pollutants are shown in Figure 2 and Figure 3

Table 4. 24-hr averaging period maximum ground level concentration of criteria pollutants and % set limits in existing refineries.

S/N	Refinery	Air Pollutant	Maximum glc ($\mu\text{g}/\text{m}^3$)	Maximum Impact Local Government Area	% Set Limit of FMENV, WB, WHO
1	Kaduna Refining & Petrochemical Company (KRPC) 110,000 BPSD	PM ₁₀	0.4	Chikun	0.2
		SO ₂	82.7	Chikun	3.2 ^a
		NO _x	404.9	Chikun	5.4 ^a
		CO	164.1	Chikun	1.4
		VOC	2.3	Chikun	0.04
2	Port Harcourt Refining Company I (PHRC) 60,000 BPSD	PM ₁₀	0.2	Eleme	0.08
		SO ₂	26.3	Eleme	1.02 ^a
		NO _x	121.4	Eleme	1.6 ^a
		CO	73.0	Eleme	0.6
		VOC	1.0	Eleme	0.02
3	Port Harcourt Refining Company II (PHRC) 150,000 BPS	PM ₁₀	0.7	Eleme	0.3
		SO ₂	111.9	Eleme	4.3 ^a
		NO _x	3,589.1	Eleme	4.7 ^a
		CO	214.9	Eleme	1.9
		VOC	17.6	Eleme	0.3
4	Warri Refining & Petrochemical Company (WRPC) 125,000 BPSD	PM ₁₀	1.7	Warri S/W	0.7
		SO ₂	444.4	Warri S/W	1.7 ^a
		NO _x	2,145.8	Warri S/W	2.9 ^a
		CO	479.2	Warri S/W	4.2
		VOC	0.9	Warri S/W	0.1

^afolds of % set limits of the standard *i.e.* above the set standard limits.

(surface plots available on request) while the Tables showing the results of maximum ground Level Concentration of air pollutant within 50 km from each of the refineries are shown in **Table 4** and the maximum ground level concentration impact from 50 km receptor locations obtained when the ground level concentration of the criteria pollutants from the refineries was compared with the set limits of Nigeria's National Ambient Air Quality Standard (NAAQS), World Bank and World Health Organization (WHO) are shown in **Table 5** and **Table 6**. The results predicted the total emissions of criteria pollutant emitted per annum in the existing and proposed refineries where NO_x has the highest rate of emissions. Also, from the existing refineries, Port Harcourt 2 refinery has the highest criteria pollutant emission rate due to its high installed capacity (150,000 bpsd) while from the proposed refineries Tonwei refinery has the highest rate of emissions of the criteria pollutant due to its high installed capacity (200,000 bpsd). It was observed that some refineries exceeds their area of influence *i.e.* the emission dispersion exceeds the plant location to the neighbouring local government area e.g. CO emissions for Rehoboth for 1 h averaging periods dispersed from Yenegoa to Ogbia. From **Table 5** and **Table 6**, criteria pollutants of ranges 0.02% - 94.5% of the standards falls within the set standards limit which means there is no health risk in the receptor locations while criteria pollutants of ranges 1.1 - 55.6 folds of the standards have exceeded the set standard limits and it means there is health risk in the receptor locations.

5. Conclusions

The ISCST3 dispersion model has been used in this study to evaluate the ground level concentrations from the

Table 5. 24-hr averaging period maximum ground level concentration of criteria pollutants and % set limits in proposed refineries.

S/N	Refinery	Air Pollutant	Maximum glc ($\mu\text{g}/\text{m}^3$)	Maximum Impact Local Government Area	% Set Limit of FMENV, WB, WHO
1	Amakpe International Refinery (12,000 bpsd)	PM ₁₀	0.04	Ikot Ekpene	0.02
		SO ₂	4.4	Ikot Ekpene	16.9
		NO _x	22.6	Ikot Ekpene	30.1
		CO	10.7	Ikot Ekpene	0.04
		VOC	0.2	Ikot Ekpene	0.002
2	Amexum Corporation (100,000 bpsd)	PM ₁₀	0.5	Akpabuyo	0.2
		SO ₂	6.7	Akpabuyo	0.4
		NO _x	314	Akpabuyo	0.4 ^a
		CO	215	Akpabuyo	1.9
		VOC	4.1	Akpabuyo	0.1
3	Antonio Oil (27,000 bpsd)	PM ₁₀	0.5	Ipokia	0.2
		SO ₂	99.4	Ipokia	3.8 ^a
		NO _x	413	Ipokia	1.5
		CO	37.5	Ipokia	0.3
		VOC	1.8	Ipokia	0.03
4	Chase Wood Consortium Nigeria Limited (70,000 bpsd)	PM ₁₀	0.5	Eket	0.2
		SO ₂	210	Eket	0.8 ^a
		NO _x	1500	Eket	2.0 ^a
		CO	170	Eket	0.01
		VOC	26	Eket	0.4
5	Clean Water Refinery (60,000 bpsd)	PM ₁₀	0.5	Eleme	0.2
		SO ₂	39.5	Eleme	1.3 ^a
		NO _x	185.5	Eleme	2.0 ^a
		CO	102.4	Eleme	0.9
		VOC	1.6	Eleme	0.02
6	Gasoline Associate & International Limited Refinery (100,000 bpsd)	PM ₁₀	0.5	Ipokia	0.2
		SO ₂	58.6	Ipokia	2.3 ^a
		NO _x	281.5	Ipokia	3.8 ^a
		CO	139.8	Ipokia	1.2
		VOC	2.1	Ipokia	0.04
7	Ilaje Refinery & Petrochemicals (100,000 bpsd)	PM ₁₀	0.8	Ilaje	0.3
		SO ₂	61	Ilaje	0.2 ^a
		NO _x	298	Ilaje	3.9 ^a
		CO	192	Ilaje	1.7
		VOC	3.0	Ilaje	0.05

Continued

8	Niger Delta Refinery & Petrochemical Limited (100,000 bpsd)	PM ₁₀	0.5	Warri South	0.2
		SO ₂	72.7	Warri South	2.8 ^a
		NO _x	347.3	Warri South	4.6 ^a
		CO	417.1	Warri South	3.7
		VOC	6.7	Warri South	0.1
9	NSP Refineries and Oil Services Limited (120,000 bpsd)	PM ₁₀	0.9	Andoni	0.4
		SO ₂	395.0	Andoni	1.5 ^a
		NO _x	1903.0	Andoni	1.3 ^a
		CO	375.0	Andoni	3.3
		VOC	6.0	Andoni	0.1
10	Ode Aye Refinery Limited (100,000 bpsd)	PM ₁₀	0.4	Okiti pupa	0.2
		SO ₂	83.5	Okiti pupa	32.1 ^a
		NO _x	440	Okiti pupa	5.9 ^a
		CO	113.8	Okiti pupa	1.0
		VOC	2.0	Okiti pupa	0.03
11	Ologbo Refinery Company Nigeria Limited (12,000 bpsd)	PM ₁₀	0.05	Ikpoba-oha	0.02
		SO ₂	0.9	Ikpoba-oha	3.5 ^a
		NO _x	8.9	Ikpoba-oha	11.8
		CO	5.0	Ikpoba-oha	0.04
		VOC	0.1	Ikpoba-oha	0.002
12	Orient Petroleum Resources Limited (55,000 bpsd)	PM ₁₀	0.7	Anambra West	0.3
		SO ₂	0.9	Anambra West	3.5
		NO _x	8.5	Anambra West	11.3
		CO	219.6	Anambra West	1.9
		VOC	3.0	Anambra West	0.01
13	Owena Oil & Gas Limited (60,000 bpsd)	PM ₁₀	0.2	Ilaje	0.08
		SO ₂	34.5	Ilaje	13.3 ^a
		NO _x	159.4	Ilaje	2.2 ^a
		CO	78	Ilaje	0.7
		VOC	1.2	Ilaje	0.02
14	Qua Petroleum Refinery Limited (100,000 bpsd)	PM ₁₀	1.0	Ibena	0.4
		SO ₂	142.5	Ibena	24.0 ^a
		NO _x	623	Ibena	8.3 ^a
		CO	423	Ibena	3.7
		VOC	6.5	Ibena	0.1

Continued

		PM ₁₀	0.05	Yenegoa	0.02
		SO ₂	2.4	Yenegoa	92.3
15	Rehoboth Natural Resources Limited (12,000 bpsd)	NO _x	12.1	Yenegoa	16.1
		CO	9.7	Yenegoa	0.1
		VOC	0.2	Yenegoa	0.003
		PM ₁₀	1.3	Ikot Abasi	0.7
		SO ₂	191.2	Ikot Abasi	8.6 ^a
16	Resources Refinery & Petrochemical Limited (100,000 bpsd)	NO _x	897.3	Ikot Abasi	14.8 ^a
		CO	399.4	Ikot Abasi	5.8
		VOC	6.0	Ikot Abasi	0.2
		PM ₁₀	0.3	Port Harcourt	0.1
		SO ₂	0.4	Port Harcourt	1.5
17	RIVGAS Petroleum & Energy Limited (30,000 bpsd)	NO _x	112.3	Port Harcourt	1.5 ^a
		CO	3.9	Port Harcourt	0.03
		VOC	1.8	Port Harcourt	0.02
		PM ₁₀	0.3	Sapele	0.1
		SO ₂	48.9	Sapele	18.8 ^a
18	Sapele Refinery Limited (100,000 bpsd)	NO _x	255.2	Sapele	3.4 ^a
		CO	48.9	Sapele	0.4
		VOC	1.6	Sapele	0.03
		PM ₁₀	0.7	Ogun water side	0.3
		SO ₂	59.4	Ogun water side	22.8 ^a
19	South West Refinery & Petrochemical Company (100,000 bpsd)	NO _x	270	Ogun water side	3.6 ^a
		CO	149.8	Ogun water side	1.3
		VOC	2.4	Ogun water side	0.04
		PM ₁₀	1.0	Eleme	0.4
		SO ₂	0.4	Eleme	1.5
20	Starrex Petroleum Refinery (100,000 bpsd)	NO _x	112.3	Eleme	1.5 ^a
		CO	3.9	Eleme	0.03
		VOC	1.8	Eleme	0.03
		PM ₁₀	1.5	Ekeremor	0.6
		SO ₂	376	Ekeremor	1.0 ^a
21	Towei Oil Refinery (200,000 bpsd)	NO _x	1875.4	Ekeremor	2.5 ^a
		CO	168.9	Ekeremor	1.5
		VOC	1.6	Ekeremor	0.03

Continued

22	Total Support Limited (12,000 bpsd)	PM ₁₀	0.7	Calabar Municipal	0.3
		SO ₂	2.9	Calabar Municipal	6.2 ^a
		NO _x	16	Calabar Municipal	21.3
		CO	22	Calabar Municipal	0.2
		VOC	0.5	Calabar Municipal	0.01
23	Union Atlantic Petroleum Refinery (100,000 bpsd)	PM ₁₀	1.8	Badagry	0.7
		SO ₂	224	Badagry	86.2 ^a
		NO _x	116.8	Badagry	1.6 ^a
		CO	658	Badagry	5.8
		VOC	10.3	Badagry	0.2

^afolds of % set limits of the standard (above the set standard limit).

Table 6. Cumulative ground level concentration impact on ambient quality of multiple refineries within each state.

S/N	Refinery	Air Pollutant	Cumulative Maximum glc (µg/m ³)	% Set Limit of FMENV, WB, WHO
1	Rehoboth Natural Resources Limited & Towei Oil Refinery Bayelsa State	PM ₁₀	1.5	0.6
		SO ₂	376	14.5 ^a
		NO _x	1875.4	25.0 ^a
		CO	168.9	1.5
		VOC	1.6	0.03
2	Total Support Limited & Amexum Corporation Cross River State	PM ₁₀	0.5	0.2
		SO ₂	7.0	2.7 ^a
		NO _x	314.4	4.2 ^a
		CO	215	1.9
		VOC	2.3	0.1
3	Antonio Oil, South West Refinery & Gasoline International Limited Refinery Ogun State	PM ₁₀	4.6	1.8
		SO ₂	107.4	4.1 ^a
		NO _x	426.4	5.7 ^a
		CO	149.8	1.7 ^a
		VOC	2.6	0.04
4	Ode Aye Refinery Limited, Ilaje Refinery & Petrochemicals & Owena Oil & Gas Limited Ondo state	PM ₁₀	0.8	0.3
		SO ₂	84.5	3.3 ^a
		NO _x	444.5	5.9 ^a
		CO	199.5	1.8
		VOC	3.0	0.05
5	Warri Refining, Niger Delta Refinery & Sapele Refinery Limited Delta State	PM ₁₀	1.7	0.7
		SO ₂	443.3	17.1 ^a
		NO _x	2145.8	28.6 ^a
		CO	480.3	4.2
		VOC	7.0	0.1

Continued

		PM ₁₀	8.0	3.2
	Amakpe International Refinery, Chase Wood Consortium	SO ₂	501	19.3 ^a
6	Nigeria Limited, Resources Refinery & Qua Petroleum Refinery Limited	NO _x	2214	29.5 ^a
	Akwa Ibom State	CO	480.3	3.7
		VOC	7.0	0.4
		PM ₁₀	0.2	0.4
	Clean Water Refinery, NSP Refineries and Oil Services Limited, RIVGAS Petroleum & Energy Limited, Starrex	SO ₂	204	7.8 ^a
7	Petroleum Refinery, Port Harcourt Refining Company I & Port Harcourt Refining Company II	NO _x	957	12.8 ^a
	River state	CO	1.6	3.5
		VOC	0.1	0.1

^a folds of % set limits of the standard *i.e.* above the set standard limit.

four existing refineries and twenty-three proposed refineries in Nigeria for the purpose of predicting the air quality impact. Emissions from minimum of seven and maximum of eleven elevated point sources of criteria pollutants with “worst case” scenario were considered. The 24-hr averaging period of ground level concentration was measured and compared with the Nigeria’s ambient quality air set limits as set by National Ambient Air Quality Standard (NAAQS), World Bank and World Health Organization (WHO) within 50 km receptor locations.

From the modeling outputs, NO_x and SO₂ are the major pollutants that exceed the set limit, hereby causing harmful effects to the environment while PM, NO_x and VOCs are within the set standard and have no effect on the environment. The highest ground level concentration predicted to be 450 - 1875 µg/m³ for 24-h averaging period was obtained at Tonwei Oil Refinery, Ekeremor Local Government, Bayelsa State, proposed to operate at installed capacity 200,000 barrels/day capacity while the lowest ground level concentration predicted to be 0.0099 - 0.1 µg/m³ for 24-h averaging period was obtained at Amakpe International Refinery, Eket Local Government, Akwa Ibom State, proposed to operate at installed capacity 12,000 barrels/day. According to Ambient Air Quality Standards (AAQS), percentage set limits of criteria air pollutants ranging from 0.02% - 94.5% are within the set standard limits and no health risk is associated with areas around the plant locations while percentage set limits of criteria pollutants ranging from 1.1 - 55.6 folds of the standards exceed the maximum permitted limits and health risk is associated with areas around the plant locations as stipulated by the National Ambient Air Quality Standard (NAAQS), World Bank and World Health Organization (WHO) emission set standards.

The study reveals that the contribution of emissions from criteria pollutant to its ambient air is significant. Possible impacts of anticipated emissions of criteria pollutants on humans [17], vegetations [18] soil and water [19] [20] are strong enough for necessary control measures to be implemented in both existing and proposed Nigerian petroleum refineries. Hence, the air quality standards guiding petroleum refinery emissions must be strictly considered, in order to ensure that the ground level concentrations do not exceed the required standard limits and prevent the adverse effect of air pollution in the Nigeria airshed.

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